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TESTING THE USE OF AEROMAGNETIC DATA FOR THE DETERMINATION OF DEPTH TO MAGNETIC BODIES IN NKALAGU AND ENVIRONS

[1]Chinwuko, A. I., [1]Benedict, O.M., [2]Obiajulu, O. O., [3]Udoh, A. C., [1]Okeke, G. C., and [1]Umeh, M.C.
(1) Department of Geophysics, Nnamdi Azikiwe University, Awka
(2) Department of Physics and Applied Physics, Nnamdi Azikiwe University, Awka
(3) Department of Geosciences, Akwa Ibom State University, Mkpat Enin, Uyo, Nigeria
Corresponding Author's Email: ai.chinwuko.edu.ng

Abstract
High resolution aeromagnetic data of Nkalagu and its environs in South-Eastern Nigeria has been acquired and analyzed using slope method, in order to determine the depth to magnetic bodies, as well as delineate the basement morphology and the structural features within the study area. The qualitative assessment of total magnetic intensity (TMI) and residual anomaly maps of the study area reveal that the study area possesses high magnetic intensities which ranges from 7890 nT to 8114 nT and -110 nT to 104 nT respectively. The analytical map reveals that the structural trend within the study area is mainly Northeast-Southwest and (NE-SW) directions which agree with the fault orientation within the Benue Trough, also The area is intensely fractured with major regional faults trending in Northeast-Southwest (NE-SW) direction. Five (5) selected magnetic profiles were taken perpendicular to the direction of the magnetic anomalies, namely K-K^1 , L-L^1 , M-M^1 , N-N^1 , and O-O^1 . The slope method analysis revealed that the study area possess a two layer depth model; the shallower and deeper bodies which varied from 1.68 km to 2.05 km and 2.84 km to 6.38 Km respectively. The basement tomography map suggest thick sediment with their contours widely spaced at the northern and Eastern parts, and shallow sediment toward the Western part with contours closely spaced. The 3-D tomography map shows the presence of peaks (uplifts) and depressions, a typical expression of folds. The findings suggest that the study area is highly fractured and possesses possible mineralization path and the existence of high Cretaceous sedimentary thickness may favour hydrocarbon accumulation.
Keywords: *Slope Method, Anambra Basin, Basement Complex, Biostratigraphy, Exploration, High Resolution Aeromagnetic Data.*

Introduction

The study area is Nkalagu and its environs in Ishielu Local Government Area, Ebonyi State, Nigeria which falls within the Southern Lower Benue Trough of Nigeria. It is underlain by a thick sedimentary sequence formed as results of series of tectonics and repetitive sedimentation in the cretaceous time (Ugwu *et al.*, 2017). Nkalagu as any other place has its own peculiar subsurface geology and mineral deposit. The Lower Benue Trough as a rift system and aulacogen (Olade, 1976) is an area of importance in terms of economic mineral deposits which Nkalagu belongs to. The marine Cenomanian - Turonian Nkalagu Formation (black shale's, limestones, and siltstones) and the interfingering regressive sandstones of the Agala and Agbani formations, rest on the Asu River Group. The limestone of Nkalagu belongs to Eze-Aku Shale Group. The study area lies between latitudes 6°00′ - 6°30′ N and longitudes 7°30′ – 8°00′ E and covering about 3,025 km (55 km by 55 km) in land mass. Figure 1: shows Location Map of the Study Area (Amajor, 1992).

Nevertheless, magnetic method is a measure of the earth's magnetic field intensity. The aim of a magnetic survey is to investigate the subsurface geology based on magnetic anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks. The aeromagnetic survey has been applied in mapping magnetic anomalies in the earth's magnetic field and correlated with the underground geological structure (Anakwuba *et al.*, 2011). Due to the complexity of data acquisition and compiling with the advent of modern technology, magnetic method is by far the most widely used of all geophysical methods, both in terms of line clinometer surveyed annually and in total (Peterson *et al.*, 1978). For exploration purposes, both ground and aeromagnetic data have been used to investigate the presence of mineral deposits in combination with gravity and or other geophysical methods.

This work aim at testing the depth to magnetic sources as well as delineating the possible intrusive alongside magnetic minerals, and determines if the area is favourable for hydrocarbon accumulation. Mineral deposits and resources are formed under certain and different circumstances and are not evenly distributed at the crust. Therefore there are need for these economic minerals to be delineated, to ascertain its shape, quantity and quality to make its exploitation economically feasible. Nowadays, Aeromagnetic surveys are very useful for determining the depth to magnetic sources over an area (that is sedimentary thickness of rocks/minerals). In the mining industry, both gravity and magnetic methods are widely used as exploration tools for mapping subsurface geology and to estimate ore reserves for some massive ore bodies. Aeromagnetic data are readily available compared to other geophysical methods; therefore the need for exploiting its potentials cannot be over-emphasized.
In this paper, both qualitative and quantitative interpretations of aeromagnetic data and production of magnetic maps were employed for testing the use of aeromagnetic data for determination of depth to magnetic bodies in Nkalagu and environs in Lower Benue Trough of Nigeria.

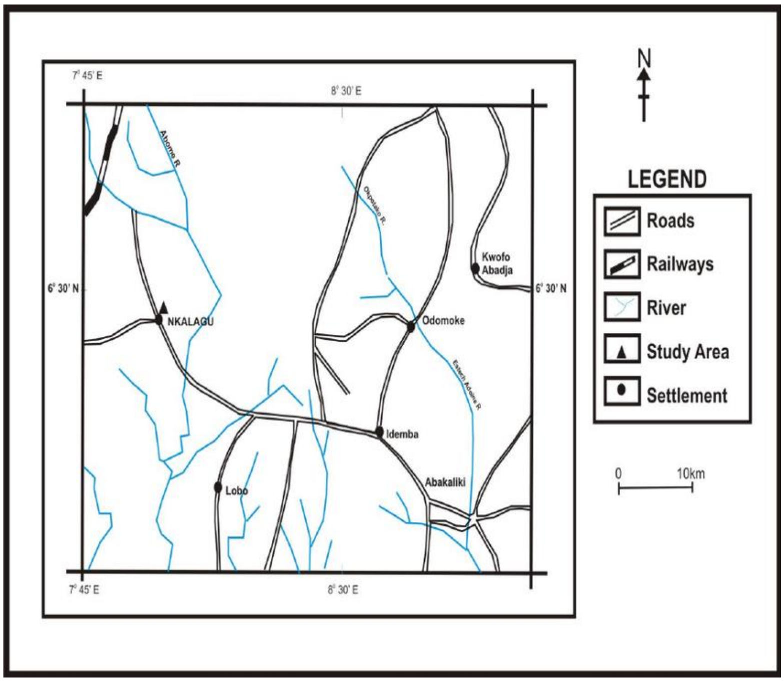

Fig. 1: Location Map of the Study Area (Amajor, 1992)

Local Geology of the Study Area

Nkalagu is a town in Ishielu Local Government Area of Ebonyi State, Nigeria. It is notable for having a large deposit of limestone which provided the raw material for the large cement plant of the Nigerian Cement Company. It is located in the South Eastern part of Nigeria. The Turonian Nkalagu Formation characterized the Mid-Cretaceous Cyclic succession of shale and limestone and it is the major shale/carbonate stratigraphic unit of the Mid-Late Cenomanian to Turonian within the Lower Benue Trough of Nigeria (Simpson 1955; Reyment, 1965; Peters *et al.*, 1982). It is exposed at the NIGERCEM (Nigerian Cement Company). The geology consists of a cyclic sequence of fossilliferious upward fining shale and limestone beds. The limestone beds thicken southwardly and grade laterally into shales toward the Abakaliki- Okigwe Anticlinorium axis to the East and North-East they became sandier and finally grade into sandstone (Umeji, 1984). The limestone of Nkalagu belongs to Eze Aku Shale Group shown in Fig. 2. It is composed of the following lithostratigraphic unit; The Asu River Group, which is the oldest (Albian Age); The Ezeaku Formation unconformable overlies the Asu River Group. It consists of alternating sandstone and hard grey to black shale. Turonian to coniacian in age. The Awgu Group (Coniacian): Large portion of the Awgu Group lies within the southern segment of the Trough, where it conformably overlies the facies of the Eze-Aku Group.

The study area is composed of the following economic minerals; limestone, shale, sandstone, clay among others used for various engineering and domestic purposes. The drainage pattern of the study area is dendritic with transitional vegetation, as the pattern grades from Guinea savannah to tropical rainforest.

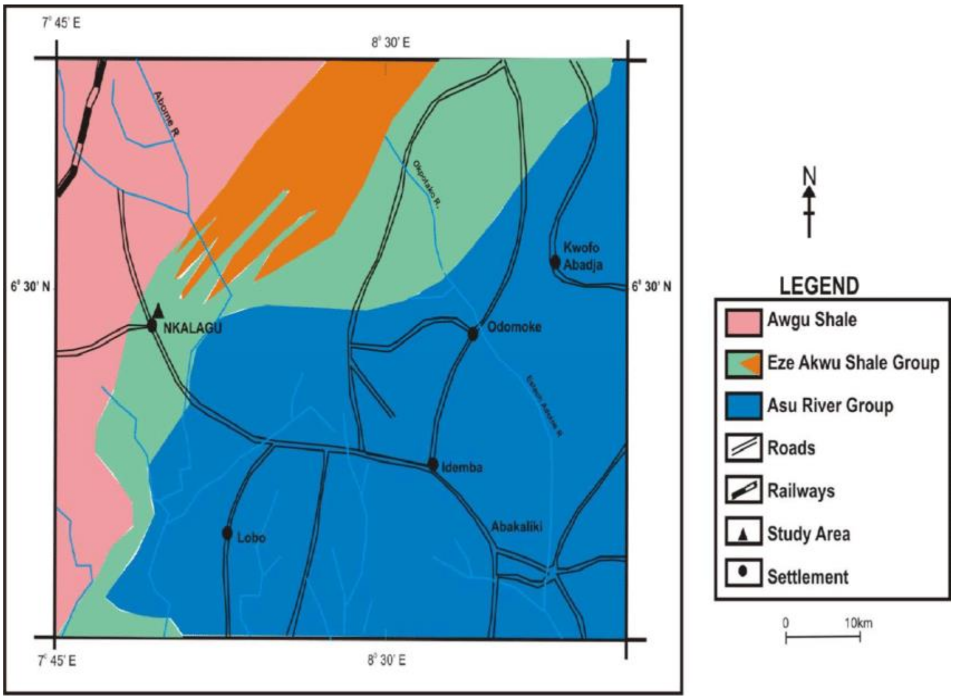

Fig. 2: Geological Map of Nkalagu Area (After, Amajor, 1992)

Methodology

Fig. 3 shows the research workflow for this study which runs from the topic to the production of the basement tomography map of the study. The methodology involved desk study where the entire related works pertaining geological framework and various aeromagnetic interpretation within and outside the study area were studied. Following this was acquisition total magnetic intensity data sheet of the study area (sheet 302) from Nigeria Geological Survey Agency at a scale of 1: 100, 000 with the areal extent as 55 x 55 km. Then, the total magnetic intensity (TMI) data was separated in order to obtain the residual anomaly data that is needed for depth calculation. Both the TMI and residual data were contoured with the aid of a contouring computer software program named Surfer-32 in order to produce the TMI map, residual anomaly map, analytical signal map, structural and lineament maps. Selected profiles were taken on the residual anomaly map for sole purpose of magnetic depth estimation using the Slope Method. Then, the calculated depth to the magnetic sources was used as input for geological modeling of the depth and generation of the basement tomography of the area.

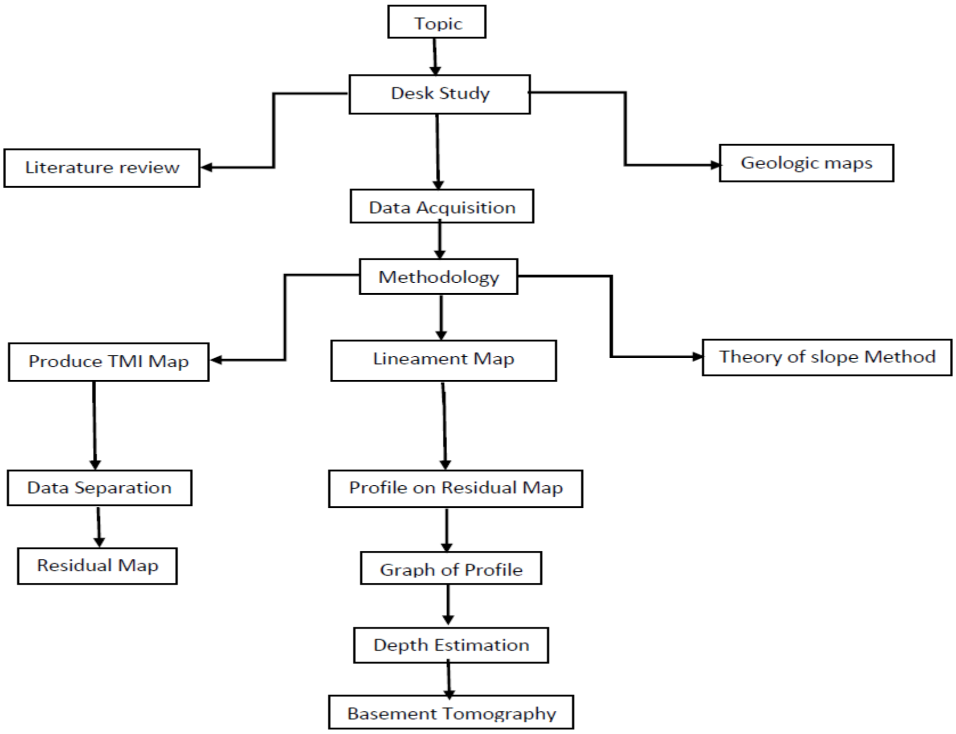

Fig. 3: Research Workflow

Results and Discussion

Qualitative Interpretation of the Aeromagnetic Maps

The total magnetic intensity (TMI), residual anomaly and analytic signal maps, are qualitatively interpreted by visual inspection of (Fig. 4) which is the Total magnetic intensity map of the study Area, and (Fig. 5) which is the Residual Magnetic Anomaly map produced after subtracting the regional magnetic field. The total magnetic field range from 7890 nanotesla (nT) to 8114 nanotesla (nT) in the study area, with higher values found in the Southeastern, Northeastern, Eastern part, and lower values towards the Western, Central, and North-west regions (Figs.4 and 5). Most of the anomalous features trend in the Northeast-Southwest and minor ones trend East-West. Chinwuko *et al.* (2012) generally believe there would always be a magnetic susceptibility contrast across a fracture zone due to oxidation of magnetite to hematite, and/or infilling of fracture planes by dyke-like bodies whose magnetic susceptibilities are different from those of their host rocks. The residual anomaly map also shows positive magnetic anomaly and larger sedimentary thickness indicating deeper depths (Fig. 5). The magnetic intensity values within the residual anomaly map range from -110nT to 110nT across the study area.

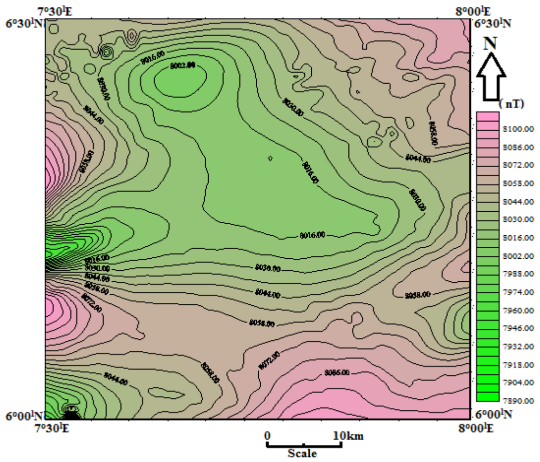

Fig. 4: Total magnetic Intensity Map of the Study Area (Contour Interval ≈ 7nT)

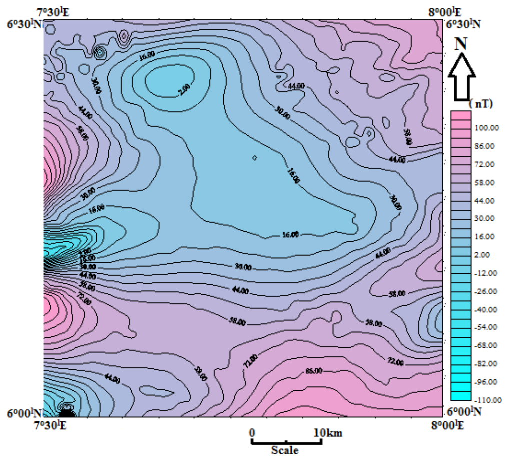

Fig. 5: Residual Map of the Study Area (Contour Interval ≈ 7nT)

The surface map (Fig. 6) has the same pattern as the TMI and Residual maps. The elliptical contour closures seen in the study area suggest the presence of magnetic bodies. These features represent geologic lineaments and their positions are indicated by lines drawn parallel to the elongation and through the centre of the anomalies. The main trend of the lineaments is Northeast-Southwest, while few trend East-West direction.

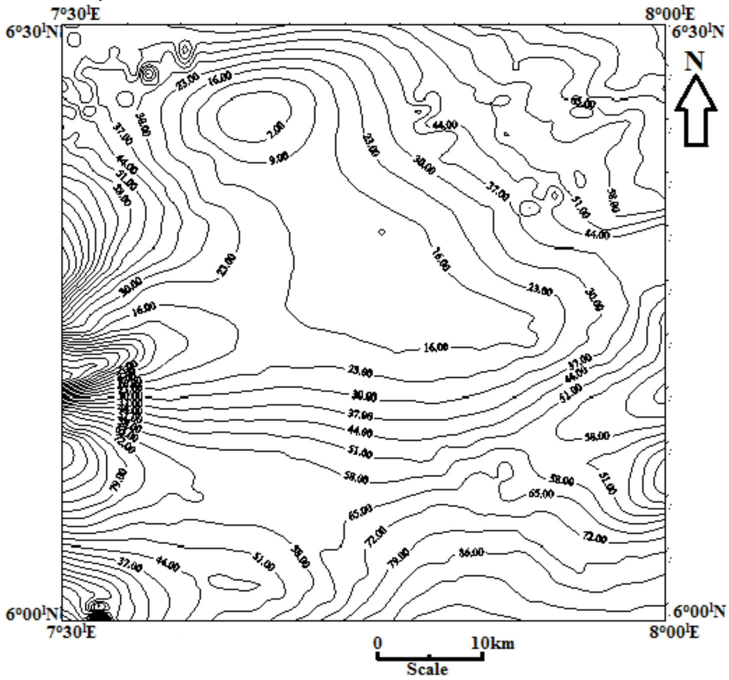

Fig. 6: Surface map (Contour Interval ≈ 7nT)

The visual inspection of the analytical signal map over the study area shows that the contour lines are widely spaced in the northern and Eastern parts which suggest thicker sediments in the region indicating that the depth to basement is higher compared to the closely spaced contours towards the Western parts which suggests shallow sedimentary thickness shown in the analytical signal map (Fig. 7). The lineament trend map shows that most of the anomalies are trending in the Northeast-Southwest direction (Fig: 8).

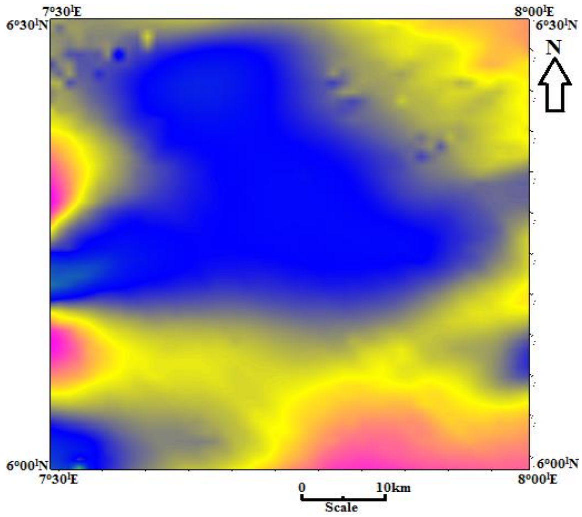

Fig.7: Analytical Signal Map of the study area (Contour Interval ≈ 7nT)

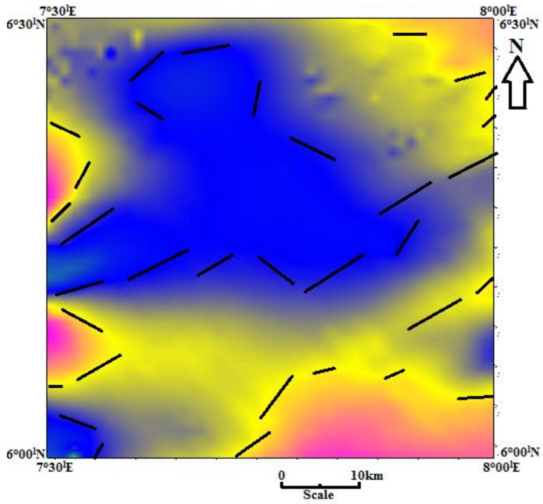

Fig. 8: Lineament Trend Map of the study area

Quantitative Interpretation

Magnetic Profiles

For the depths to basement (sedimentary thickness) to be obtained across the study area using the slope method, several profiles were taken on the residual aeromagnetic anomaly map of the study area (Fig. 9). Five selected magnetic profiles were taken perpendicular to the direction of the magnetic anomalies, namely K-K′, L-L′, M-M′, N-N′, and O-O′, which were used for detailed interpretation and these serve as representatives of others since they behave almost the same way.

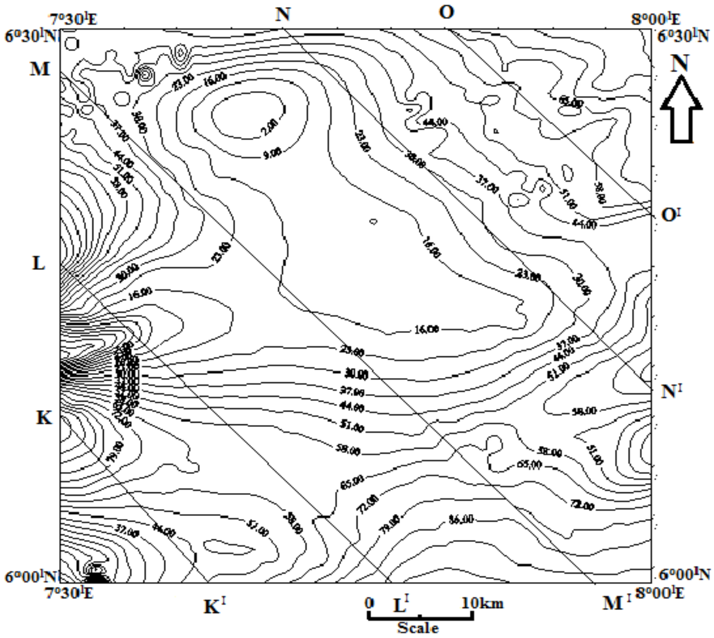

Fig. 9: Profiles along residual anomaly map of the study area (Contour Interval ≈ 7nT)

Estimating Depth to Magnetic Bodies

The study area possess a two layer depth model; the shallower bodies which vary from 1.68 km to 2.05 km; the deeper bodies vary from 2.84 km to 6.38 Km, through the application of Peter's slope method for depth to the top of the magnetic body as shown in Table 1. The Table also shows a summary of basement depths obtained from Slope method carried out in the study area. Basement depths along profile K-K′ range from 2.05 km to 3.25 km, along L-L′ the depths range from 1.68 km to 3.80 km, 2.84 km to 5.89 km along M-M′, along profiles N-N^{I} is 5.64 km to 6.11 km, and it is 6.38 km along O-O^{I} profile respectively.

Table.1: Depth to the Magnetic Bodies obtained from the Slope method

ANOMALY	PROFILE	X	Y	DEPTH (km)
1	K – K′	0	4.3	2.05
2		3.1	0	3.25
3	L – L′	1.8	7	1.68
4		6.5	2	3.8
5		0.9	13.3	2.84
6	M – M′	6	8	5.17
7		13.4	0.2	5.89
8		7	15	6.11
9	N – N′	10.3	10.5	5.64
10		12.5	8.2	5.88
11		15	5.6	5.61
12	O – O′	12.4	12.9	6.38
Average				4.53

Depth Modelling of the Anomalies along the Profile

The geological model of the anomalies shows that the study area is intensely fractured with shallow and thick sediment as shown in Fig. 10. These models were established using the depth values determined from the peters half-slope analysis method and models. The deeper magnetic sources vary from 2.84 km to 6.38 km, whereas the shallow magnetic sources vary from 1.68 km to 2.05 km (Table 1). Deeper magnetic sources may probably represent depths to Pre-Cambrian basement, while the shallower magnetic sources may represent depths to basic intrusive and/or magnetized bodies within the sedimentary cover.

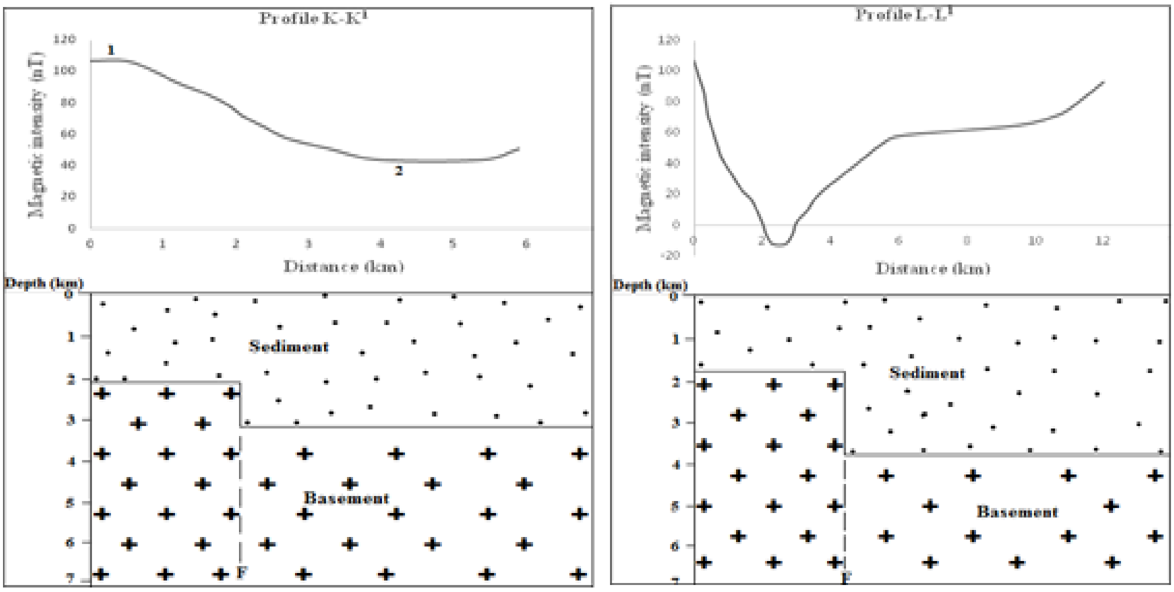

Fig. 10a: Geological Model within the Study Area along Profile K-K′ and L-L′.

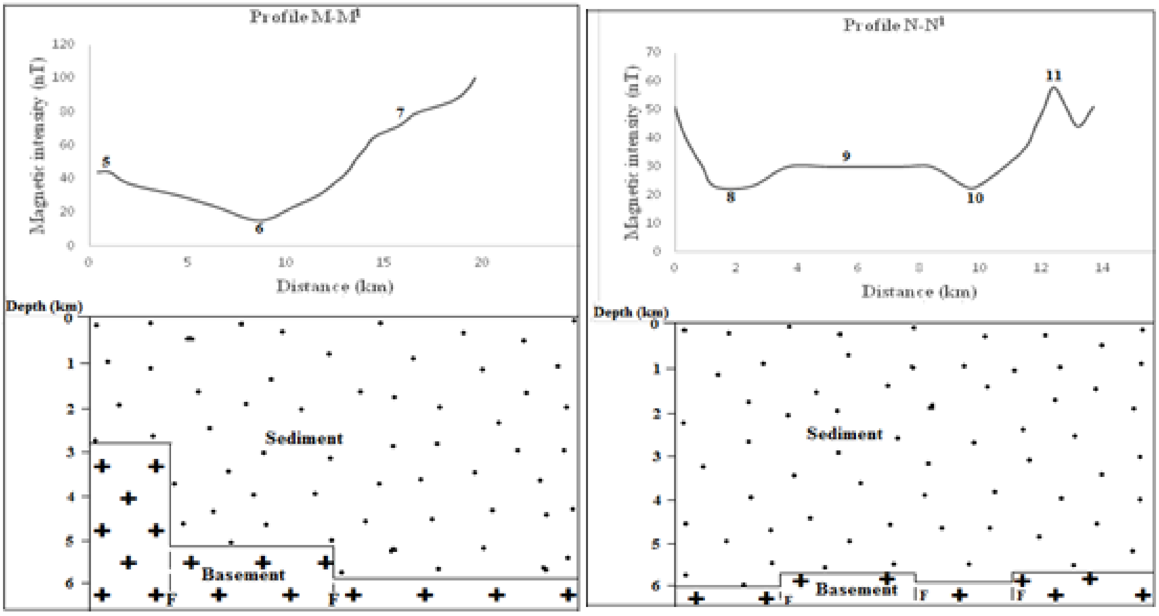

Fig. 10 b: Geological Models within the Study Area along Profile M-M^1 and N-N^1.

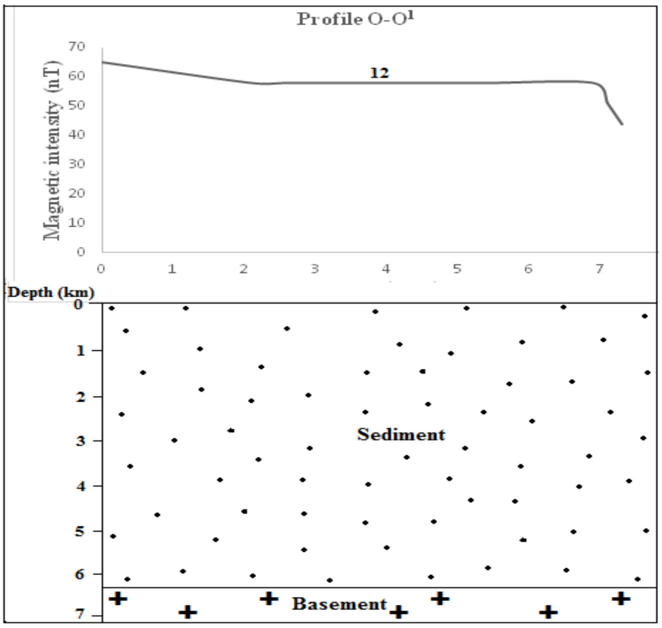

Fig. 10c: Geological Model within the Study Area along Profile O-O^1.

Basement Tomography

Two depth models were established using the depth values determined from the Peter's half-slope analysis method and models. The deeper magnetic sources vary from 2.84 km to 6.38 km, whereas the shallow magnetic sources vary from 1.68 km to 2.05 km (Table 1). Deeper magnetic sources may probably represent depths to the Precambrian basement, while the shallower magnetic sources may represent depths to basic intrusive and/or magnetized bodies within the sedimentary cover (Chinwuko *et al*., 2012; Okonkwo *et al*., 2020). The deeper depth of basement is in the eastern and northeastern parts of the study area which is represented by sky-blue colour whereas, the shallower depth is in the Western part of the study area as seen in the basement map (Fig. 11). This map gives the basement configuration as well as the sedimentary thicknesses within the study area.

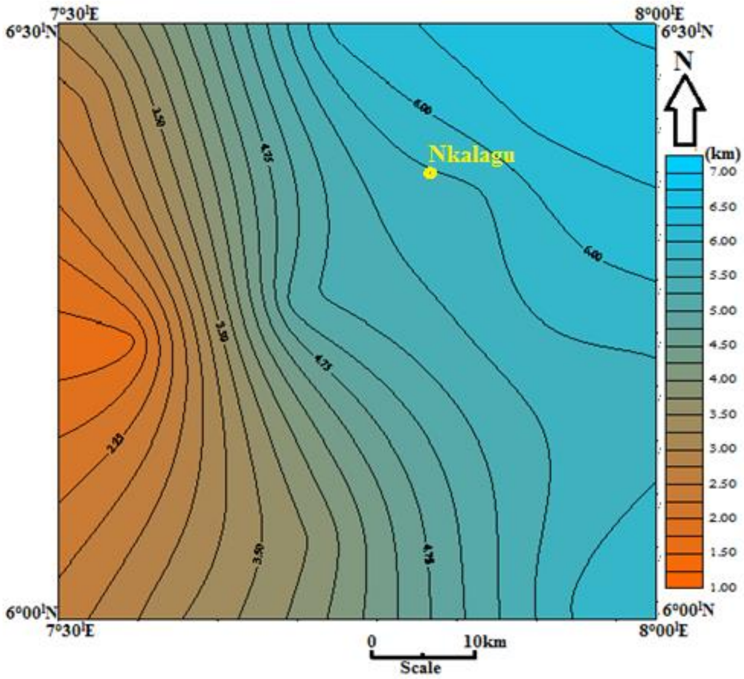

Fig. 11: Depth to Basement Map of the Study Area

The 3-D surface plot shows a linear depression at the Western part of the study area indicating shallow sediments which trend Northeast-Southwest direction while the Eastern and Northern parts have thicker sedimentary thicknesses (Fig. 12). These peaks and depressions in Fig. 12 are typical expression of folds. This folding could be linked to the basin fill which comprises a northwestern trending belt of Upper Cretaceous sedimentary rocks.

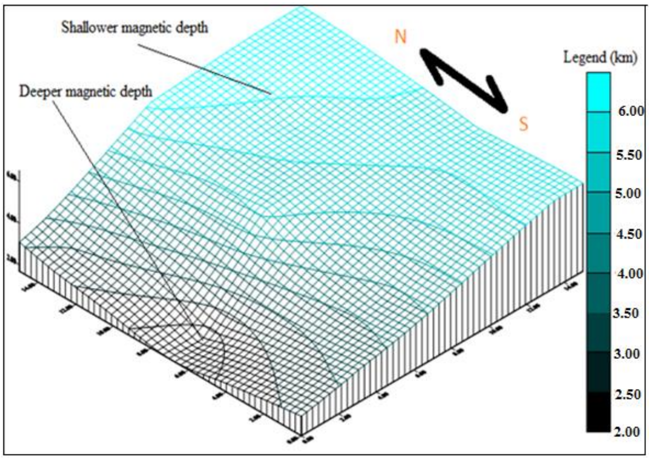

Fig 12: 3-D Model of the Basement Map

Mineral and Hydrocarbon Potentials Implication

The elliptical contour closures seen in the study area suggest the presence of magnetic bodies. These features represent geologic lineaments and their positions are indicated by lines drawn parallel to the elongation and through the center of the anomalies. The main trend of the lineaments is Northeast-Southwest, while few trend East-West direction. Invariably, all the mineralization in the study will trend in this particular direction and this assertion is in line with the work of Okonkwo *et al*. (2020) in the Bida Basin. More so, the study area has an average depth to the magnetic bodies of 4.53km which is an indication that the study possesses huge sedimentary cover that could favour hydrocarbon accumulation within the study area. This is supported the works of Anakwuba and Chinwuko (2012) along with Chinwuko *et al.* (2015) which suggest that those thick sedimentary covers with minimum of 2.0km are favourable for hydrocarbon accumulation.

Conclusions

After the aeromagnetic anomaly data has been analyzed and interpreted using the slope method and the following conclusions were reached; the visual assessment of total magnetic intensity (TMI) and residual anomaly maps of the study area reveal that the study area possess high magnetic intensities which ranges from 7890 nT to 8114 nT and -110 nT to 104 nT respectively. Also, the elliptical contour closures seen in the study area suggest the presence of magnetic bodies. The area is intensely fractured with major regional faults trending in Northeast-Southwest (NE-SW) direction. Two depth sources were obtained from the interpretation of the residual anomaly map; the deeper magnetic sources vary from 2.84 km to 6.38 km, whereas the shallow magnetic sources vary from 1.68 km to 2.05 km. The generated basement map gives the basement configuration as well as the sedimentary thicknesses within the study area. The 3D surface map of the basement map reveals the presence of peaks (uplifts) and depressions, a typical expression of folds. More so, the study area has a huge sedimentary cover that could favour hydrocarbon accumulation within the study area.

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